EDGEWOOD ARSENAL
TECHNICAL REPORT

EATR 4193

ENDURANCE OF OVERHEATED MEN IN EXHAUSTING WORK

by

F. N. Craig
H. L. Froehlich

July 1968

DEPARTMENT OF THE ARMY
EDGEWOOD ARSENAL
Research Laboratories
Medical Research Laboratory
Edgewood Arsenal, Maryland 21010

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Task 1B622401A09708

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FOREWORD

The work described in this report was authorized under Task 1B622401A09708, General Investigations (U), Work Unit -01 Evaluation of Protective Equipment (U) and Research Plan No. 14077, Physiological Investigation and evaluation of Protective Equipment (U) and Research Plan No. 14133, Applied and Environmental Physiology of Defense Against Chemical Agents (U). The data were collected between 1 June 1966 and 20 February 1967.

The volunteers in these tests are enlisted US Army personnel. These tests are governed by the principles, policies, and rules for medical volunteers as established in AR 70-25.

Acknowledgments

The authors are indebted to the volunteers for generous and wholehearted cooperation, to the Clinical Research Department for furnishing the volunteers and their medical supervision, to the Biostatistics Office for computer service, and to W.V. Blevins, C.R. Bulette, R.J. Leidell, and G.S. LaRussa for assistance.

DIGEST

Illustrative data have been obtained to show how the capacity for exhausting work in a standard treadmill task can be degraded by initial overheating of the body.

The endurance of men engaged in exhausting work on a treadmill is strongly influenced by the body temperature at the beginning of the work. The higher the initial rectal temperature, the shorter is the endurance.

In three groups of four men, the regression of voluntary walking time on rectal temperature was highly significant, with coefficients of correlation of -0.96, -0.79, and -0.86, respectively. From these regressions it can be predicted that at an initial rectal temperature of 41°C, men would be unable to work.

Exhaustion appears to be reached at a maximal heart rate (average 201). The voluntary walking time is closely correlated with the standing heart rate before work is begun (-0.83). From the regression of walking time on standing heart rate, it is predicted that walking time would be zero at a standing heart rate of 205 beats per minute.

Endurance of overheated men engaged in exhausting work appears to be limited by circulatory factors rather than by body temperature, for the average final heart rate only varied from 200 to 203, whereas the final rectal temperature varied from 37.6 to 39.2°C when the men were subjected to different degrees of initial overheating.

When the endurance was diminished by overheating, the wearing of the M17 field protective mask did not alter the endurance, perhaps because maximal work rates were not attained.

In order to maintain the maximum capacity for exhausting work, troops in the field must avoid overheating as well as dehydration.

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ENDURANCE OF OVERHEATED MEN IN EXHAUSTING WORK

I. INTRODUCTION.

In the course of an evaluation of the Drinking Device, Field Protective Mask, E47, soldiers who restricted their intake of water during a 5-hour exposure to heat suffered an increase in body temperature and a decrease in their capacity to perform exhausting work. However, soldiers with water available failed to drink enough to replace the water lost in sweat so that data were not obtained for the work capacity of fully hydrated men.[1] This is the report of experiments to investigate the effect of an initial elevation in body temperature on the capacity to do exhausting work in the absence of dehydration. This experiment is to be distinguished from experiments in which subjects begin work with a normal body temperature and become heated as the work progresses in a warm environment.

In addition to serving as controls for the previous experiment, the results may have a wider interest. Even though the Drinking Device makes it possible to avoid dehydration during operations with chemical weapons systems, overheating may still be encountered because of the interference with the loss of heat from the body associated with protective clothing, the large quantities of heat produced in the body during hard work, and the inhibition of sweat production by the therapeutic use of atropine.

Four series of experiments are described in the report. In the first series, three experiments were performed on one man to examine the effect of raising the body temperature on respiration and gas exchange during exercise and in the absence of dehydration. In the second series four men worked to exhaustion after they were heated by means of enclosure in a plastic bag. In one experiment the men were bareheaded and in the other they wore the M17 field protective mask. The purpose was to test whether the conditions were favorable for the study of the decrease in work performance associated with the respiratory resistance of the mask. In the third series four men, who were heated by means of enclosure in a plastic bag, were studied to obtain additional data on endurance at different levels of body temperature with and without drinking water during the period of heating. Tests at 18°C were also made before and after the tests at 46°C to examine the effects of training in the heat on endurance in a cool environment. In the fourth series four men were heated in a tub of warm water to five predetermined levels of body temperature in order to obtain a better range of the variable. Also, training tests at 18°C were made, five before and one after the five tests at 46°C.

II. METHODS.

Two environmental conditions were maintained in an air conditioned room with minimal air movement: dry bulb 18°C, wet bulb 13°C; and dry bulb 46°C, wet bulb 23°C. In series II, III, and IV, the subjects were enlisted men drawn temporarily from US Army areas within the United States of America (table I, appendix). These men were recruited without coercion or enticement and were free to withdraw from the experiment at any time. Their participation was governed by appropriate medical safeguards. The men wore socks and their own combat boots. Thermocouples in open rings and electrodes for the electrocardiograph were supported on rubber straps. The thermocouples were placed on the front and back of the chest, the hip, and the thigh just above the knee. A rectal thermocouple was placed at a depth of 7.5 cm. In the cool environment the men also wore cotton undershirts and shorts.

After procedures to be described below, each man stood while heart rate and temperature were taken. At the end of a two-minute standing period, the men started walking on a treadmill at an initial grade of 10 percent. The grade was increased by 1 percent at the end of each minute. The treadmill speed was 1.5 m/sec (3.5 mph). Walking continued to exhaustion. The men did not push themselves to the point of collapse, after halting they were able to remain on their feet by holding onto the rail. The thermocouples were read at intervals of 64 seconds. The electrocardiogram was recorded continuously and the rate was counted over intervals of 15 seconds. The standing heart rate and temperatures were averaged over the initial period of two minutes before the onset of walking.

Series I. Respiratory measurements were made according to the procedure described previously.[1] On entering the room, the man stood for two minutes while preliminary data were recorded. He rested for about an hour on a cot and then stood to begin the walking test. In the tests at 46°C, he drank water at intervals of ten minutes. On one day he was enclosed up to the neck in a plastic bag to minimize evaporative heat loss during the rest period.

Series II. In this and the later series, no respiratory measurements were made. There was a rest period of an hour before the walk. Boots were removed during the rest period. Overheating was induced by enclosing the man in a plastic bag up to the neck during the rest period on days indicated in table II (appendix). The man drank water at intervals while in the bag, but the amounts were not controlled. On one of the days on which the bag was used, the men wore an M17 field protective mask.

Series III. The preliminary rest period was an hour. Tests were made with and without the bag and with and without water on paired days (table II, appendix). During the rest period on days 3 and 8, two men were in the bag and on days 10 and 15 the other two men were in the bag. When supplied, water was given in amounts of 500 ml at the beginning of the rest period and 100 ml at 20, 30, 40, 50, and 60 minutes. The men were weighed before and after the rest period. The temperature of the drinking water was 10°C in contrast to the temperature of 46°C of the water in the earlier 5-hour heat exposures.[1] According to calculation, the use of cold water could have reduced the mean body temperature by 0.5°C.

Series IV. In this series overheating was induced by immersion up to the neck in a tub of water at about 43°C. The men rested for 30 minutes before entering the hot room. At the beginning of the rest period they drank 500 ml of water at 10°C. On entering the room the man was weighed and stood for two minutes while preliminary measurements were recorded. He then reclined in the tub until the desired rectal temperature was reached. The target temperatures for successive days were 37.2, 37.8, 38.3, 38.9, and 39.2°C. The period in the tub varied from 2 to 30 minutes. If the rectal temperature rose faster than 0.1°C per minute the subject was asked to sit up to reduce the body surface covered by water. After drying, weighing, and a delay for donning socks and shoes, he stood for two minutes and then began to walk.

III. RESULTS.

Series I. The results of tests on one man under three thermal conditions without dehydration are given in figure 1. Increases in respiratory minute volume and frequency, the ratio of ventilation to oxygen intake, the decreases in oxygen extraction, and the concentration of carbon dioxide in mixed expired air gave evidence of hyperventilation. Since the results were qualitatively similar to those reported for the dehydration series,[1] respiratory measurements were omitted in Series II, III, and IV.

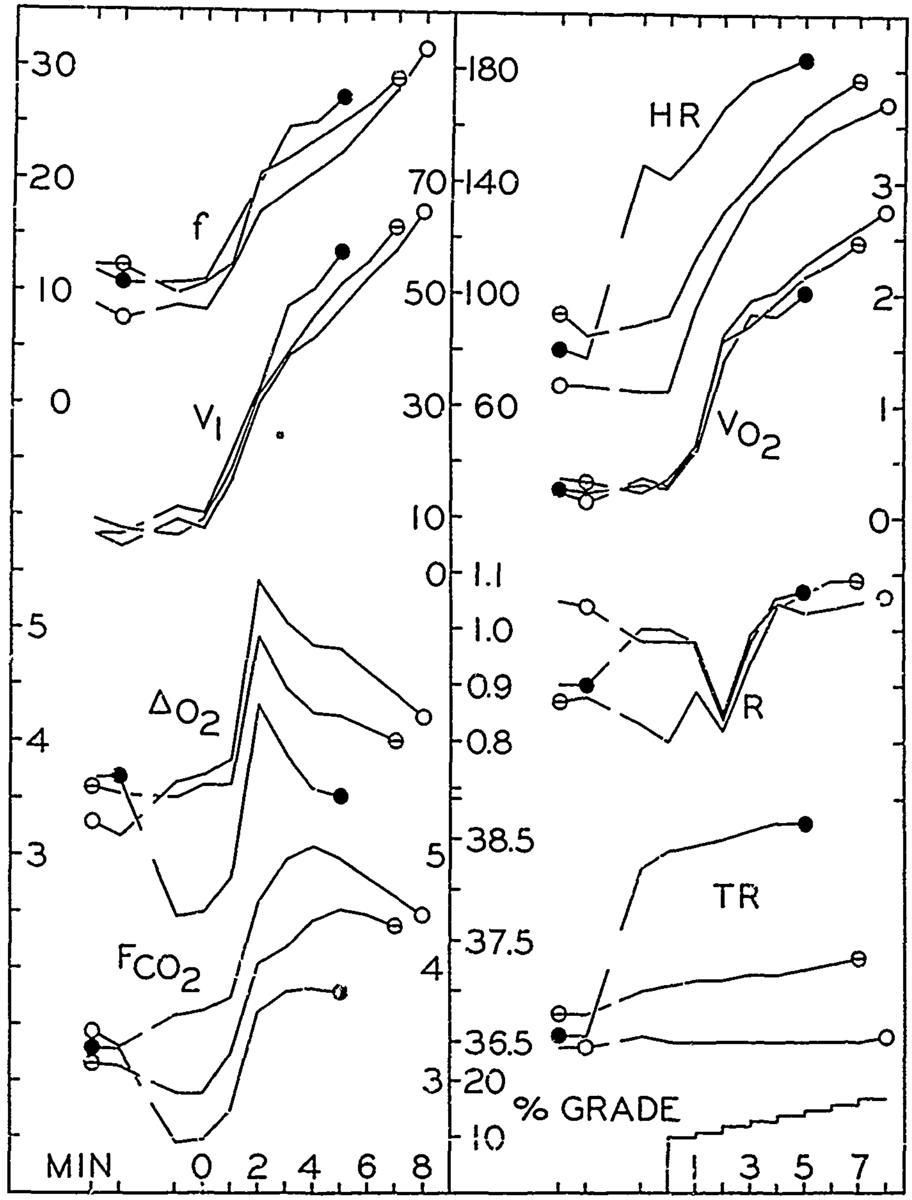

Figure 1. Results for FC in Series I Averaged for Each Minute During Standing and Walking.

The rest period came in the gap in the time scale. The open circles represent the experiment at 18°C, the horizontal bars represent the experiment at 46°C without the bag and the closed circles the experiment at 46°C with the bag. In the left panel, from the top down, are respiratory frequency in breaths per minute (f), inspired minute volume in liters per minute at STPD (V_I), the difference in fraction of oxygen between inspired and expired air in volumes percent (ΔO_2) and the fraction of carbon dioxide in mixed expired air in volumes percent (FCO_2). In the right panel, from the top down, are heart rate in beats per minute (HR), the oxygen intake in liters per minute at STPD (VO_2), the respiratory exchange ratio (R), the rectal temperature in °C (TR), and the slope of the treadmill.

Series II. After control observations at 18° and 46°C, two similar tests were made after heating by means of enclosure in the plastic bag. Moderate amounts of water were drunk by the men while in the bag but sweating was not measured (table II, appendix). The walking time was sharply reduced at the higher rectal temperatures. On day 9, every man walked longer than on day 7. In the experiments at 46°C the walking times were converted to a percentage of the longest time. The regression of percent walking time on rectal temperature in standing immediately before the walk appears in figure 2.

On day 7 two men wore the M17 field protective mask during the walk and on day 9 the other two men wore the mask. The individual results listed in table III (appendix) show considerable variation in performance from man to man and from day to day, but in the group averages, the mask had no significant effect.

Series III. Sweat production during the rest period at 46°C before the walk produced a dehydration of one percent or less of the body weight with or without the bag (table II, appendix). Drinking a liter of cold water reduced the increase in body temperature and prolonged walking time. Longer walking times were again obtained at 18° than at 46°C. The walking time at 18° increased 15 percent from day 1 to day 17 (table II, appendix) and equal work was performed at the cost of 5 percent fewer beats of the heart. Blanching of the skin of the face and neck was observed in one man at the end of the shortest walk in this series (156 sec). In the experiments at 46°C the walking times were converted to a percentage of the longest time. The regression of percent walking time on rectal temperature on standing immediately before the walk appears in figure 2.

Series IV. Tests were performed at 18°C, five before and one after the tests at 46°C. The increase in walking time before the tests at 46° was only 5 percent and there was little change after the tests at 46° (table IV, appendix). Also, there was a less consistent change in the pulse sum for identical periods of walking before and after the tests at 18° and at 46° than in Series III. Data in table II (appendix) show that in this series the weight lost in the tub was less than the preliminary water intake of 500 gm so that dehydration was minimal.

Results of one test with the tub are given in figure 3 to show the general course of the experiment and the fluctuations in water temperature, skin temperature (hip only), rectal temperature and heart rate. Individual results in figure 2 show the decline in walking time as a percentage of the longest time at 46° with increasing rectal temperatures in the standing period before the walk.

Individual data for standing and final heart rate are plotted against walking time in figure 4. The regression line for standing heart rate reached zero walking time at 205 beats per minute which is close to the average final heart rate of 201 for the tub tests. The intercept of the regression for standing rectal temperature at zero walking time was 40.9°C or 105.8°F which is too close to the temperatures seen in heat stroke to invite experimental validation. A temperature of 106°F is sometimes cited as the beginning of the range of heat stroke. However, rectal temperatures of 41°C have been recorded in winning marathon runners.[3]

In figure 5 the heart rate counted over periods of 15 seconds was plotted against time for the last 2 or 3 minutes of each walk at 46°C. In some tests the final rate was no greater than the immediately preceding rate, however, similar irregularities in the increase in rate were common earlier in the walk so that it was judged that the rate did not level off. Lines drawn by eye to indicate the trend of the increase had slopes of about 2 or 3 beats per minute. In order to correct

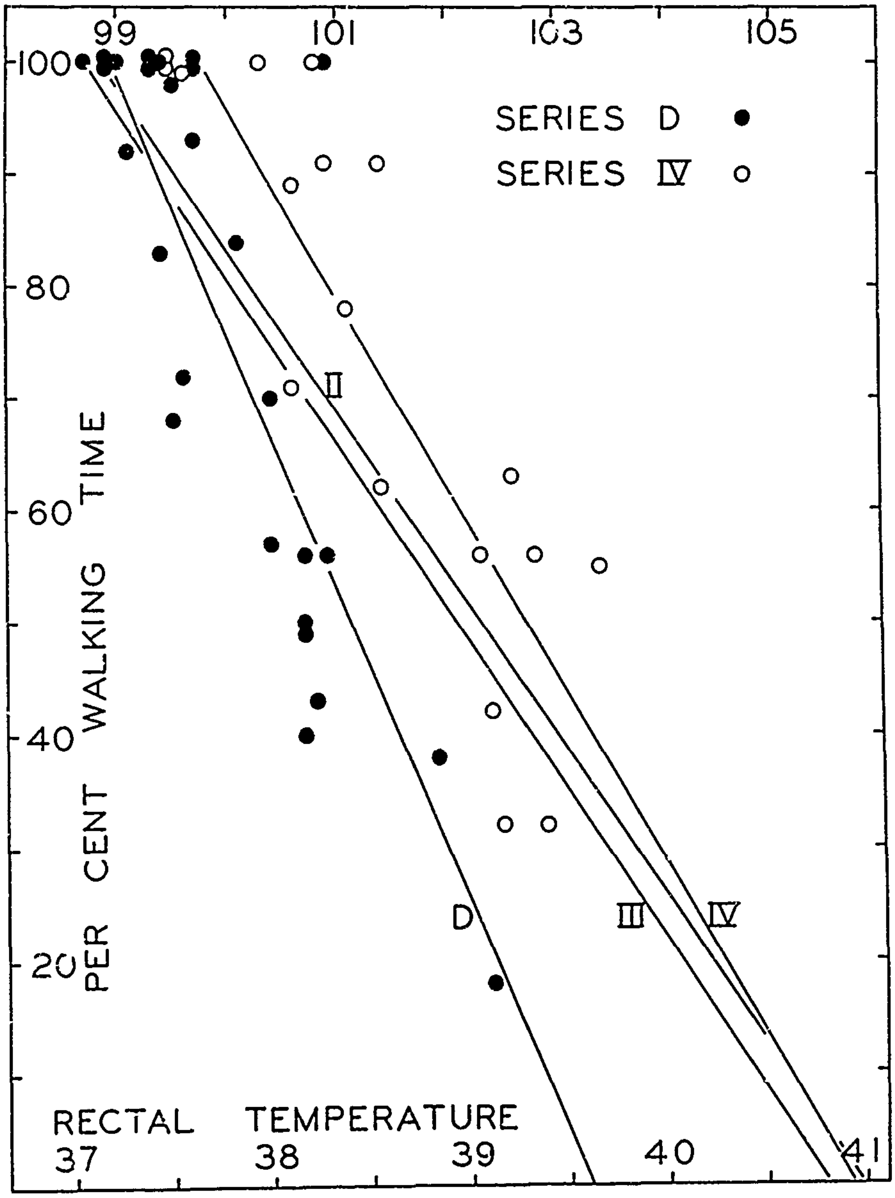

Figure 2. Walking Times at 46° converted to a Percentage of the Longest Walking Time for Each Man, and Rectal Temperature on Standing Immediately Before the Walk.

Results for Series II and III appear as regression lines marked II and III. Results for Series IV are given as individual data (open circles) and as the regression line marked IV. Results for the earlier dehydration series[1] are given as individual data (closed circles) and as the regression line marked D.

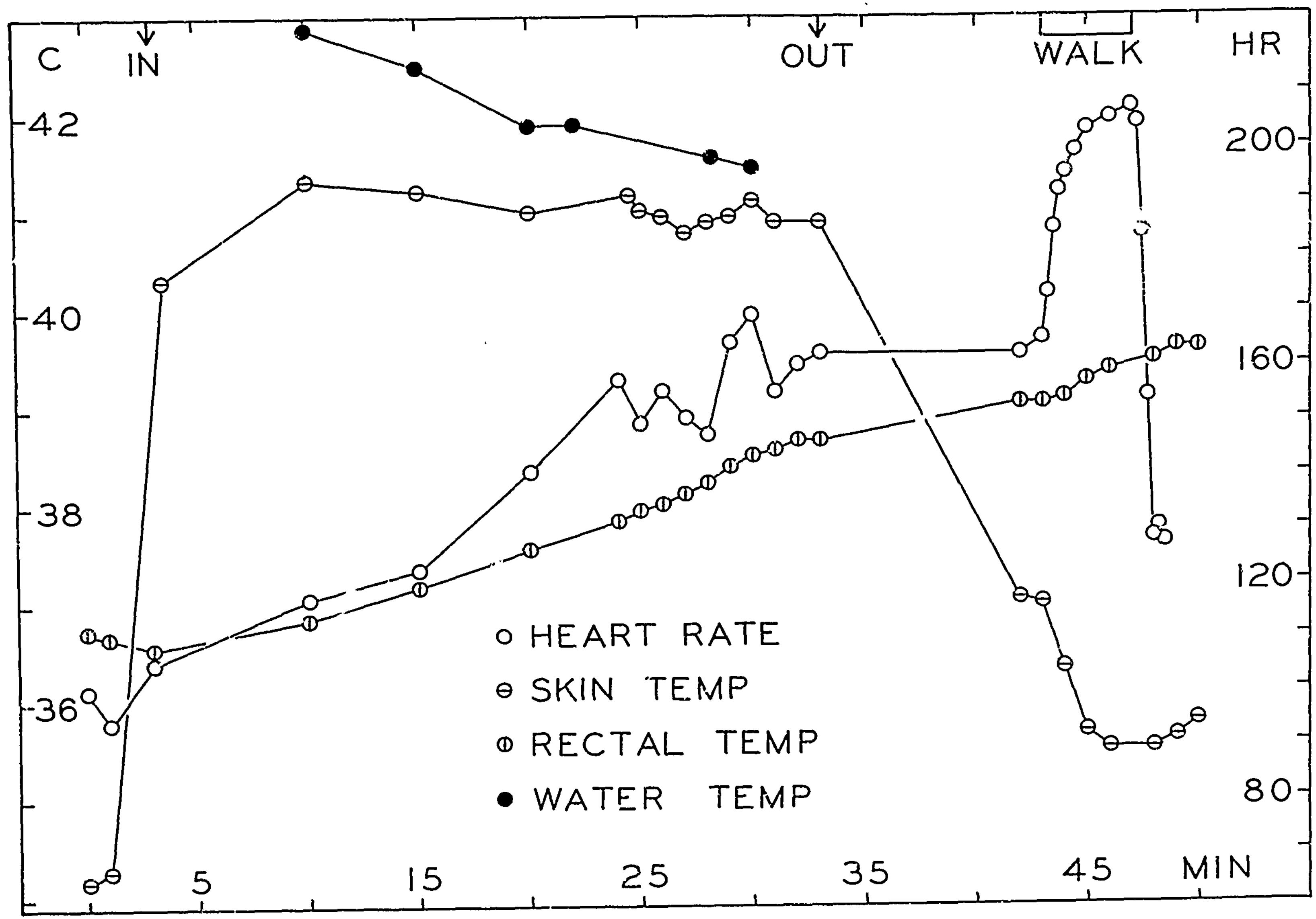

Figure 3. Results for One Test on DB in Series IV to Show Changes With Time in Temperature of the Bath Water, Skin Temperature on the Hip, Rectal Temperature and Heart Rate.

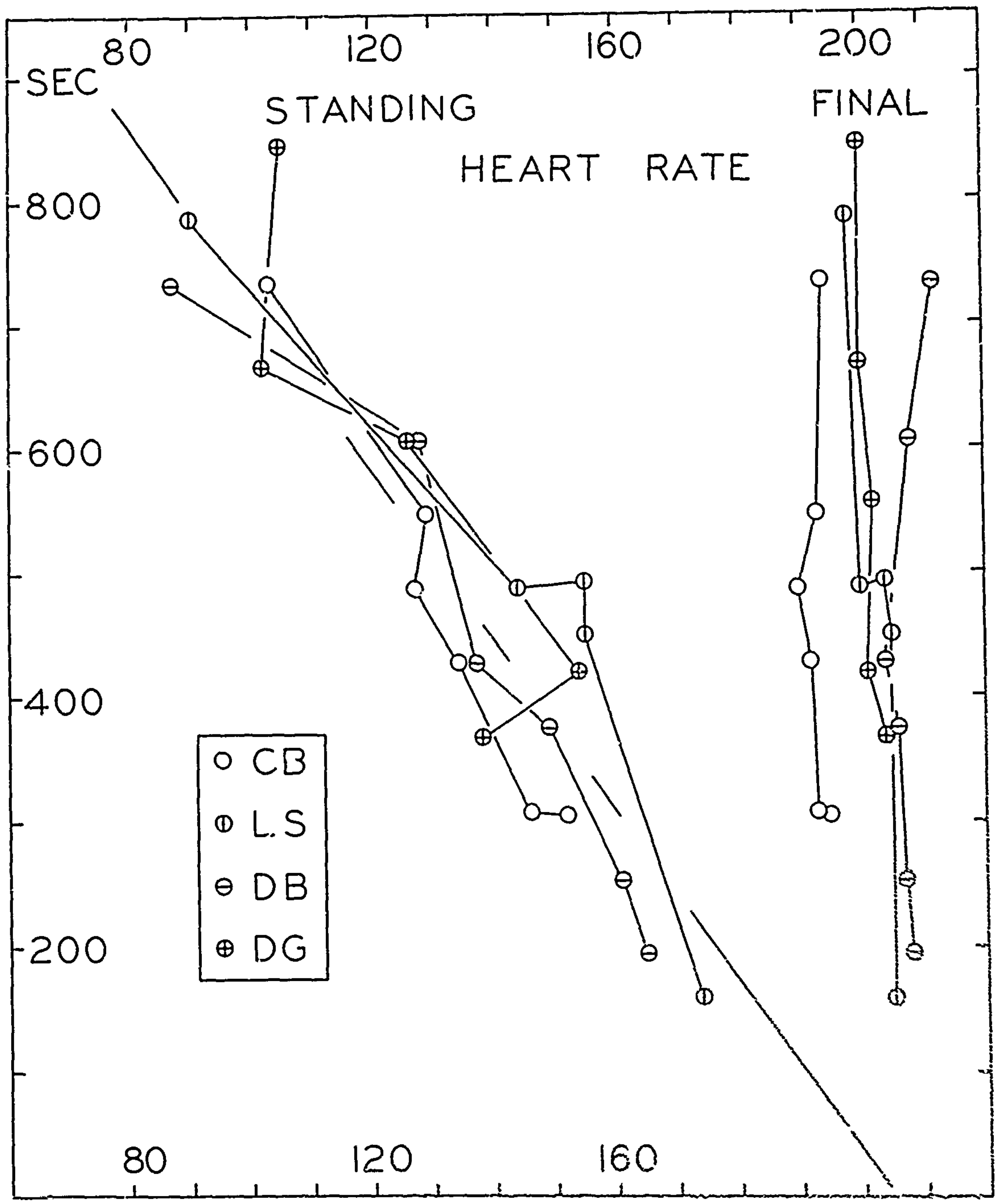

Figure 4. Heart Rate During Two Minutes of Standing Before the Walk and During the Last 15 Seconds of the Walk Plotted Against the Walking Time in Seconds.

The four longest times come from the best practice walk for each man at 18°C. Data for the line of regression appear in table 5.

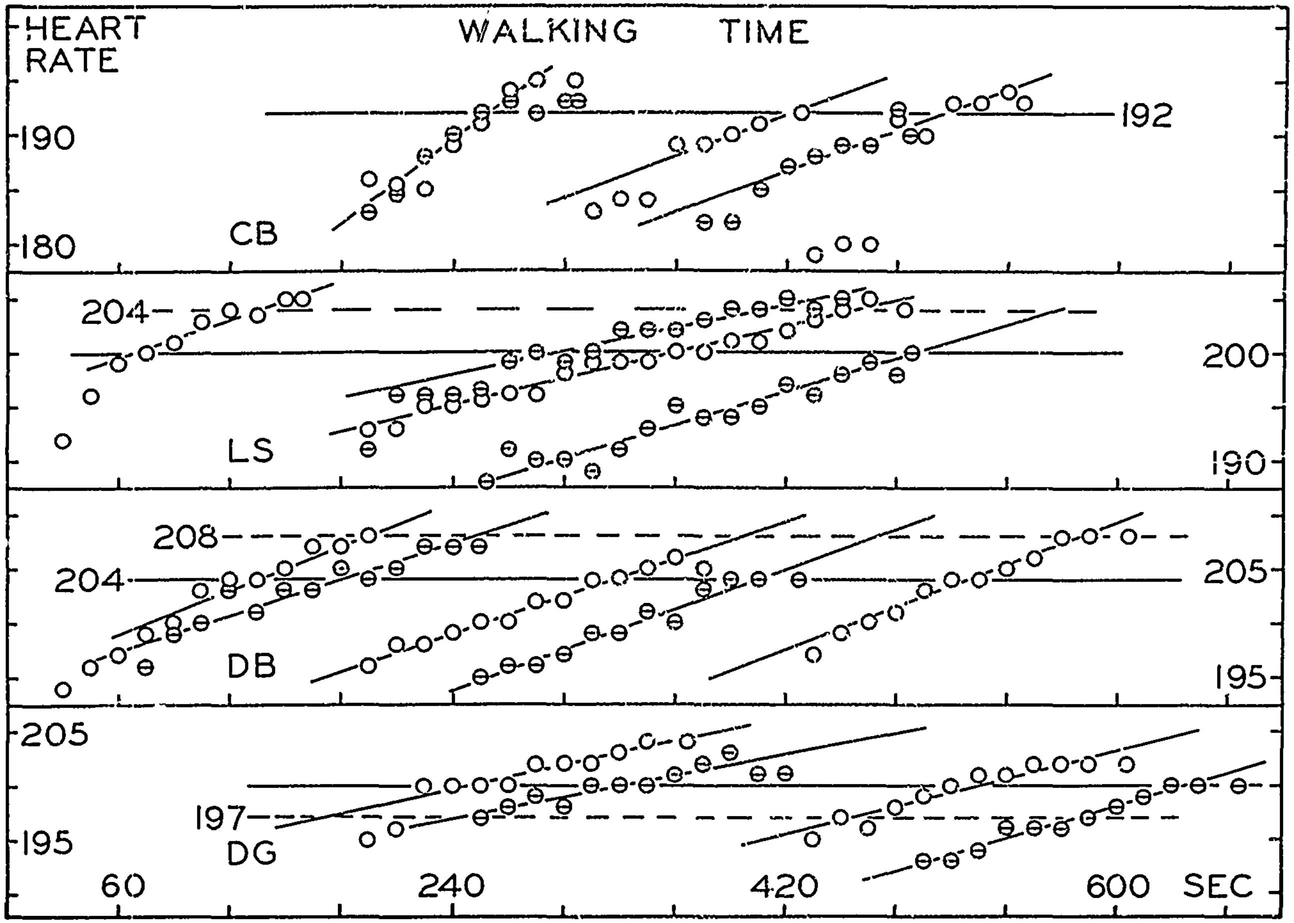

Figure 5. Heart Rate in Periods of 15 Seconds During the Last 2 or 3 Minutes of Each Walk Grouped by Men.

A straight line was fitted by eye for each walk. The solid horizontal lines were drawn through the lowest final rate for each man to permit comparison of the time to reach this rate from one walk to another in the same man by interpolation. The dashed horizontal lines were drawn at heart rates selected arbitrarily. The walking times estimated for these heart rates are related to rectal temperature in the regressions in table 5.

for day-to-day changes in motivation or errors in judging the end-point, walking times were obtained by interpolation at the intersection between the sloping lines fitted to the heart rates and a horizontal line drawn through the lowest final rate for each man. These walking times were related to the standing rectal temperature in the regression in table V (appendix) marked "interpolated." In order to bring subjects into better agreement, additional criterion lines (the broken lines in figure 5) were drawn horizontally through arbitrarily selected heart rates. A separate group of walking times was defined by the intersections between the sloping lines fitted to the heart rates for LS, DB, and DG, and the horizontal broken lines. These walking times plus those obtained by the first procedure for subject CB were related to the standing rectal temperatures in the regression in table V marked "extrapolated." The regression for the group now had a correlation of 0.98 without significant change in slope (table V, appendix). The effect of this procedure was to reduce the variance from factors other than body temperature to 3.3 percent.

The average skin temperature fell when the man left the tub and again when walking began. It was about 1.4°C lower in the third minute (table V, appendix), but did not change greatly during the remainder of the walk. The slopes of the lines of regression of skin temperature compared with rectal temperature were not significantly different (table V, appendix). The rectal temperature increased by about 0.5°C during the change from the tub to the standing position and rose another 0.3°C during the walk as may be seen from the intercepts of the regressions of walking time on rectal temperature in table V (appendix).

The difference between rectal and skin temperatures decreased sharply when the environmental temperature was changed from 18° to 46°C (figure 6). At 46° the difference between rectal and skin temperatures increased after the onset of walking (figure 6). The difference between rectal and skin temperatures increased with increasing rectal temperature both in standing and in the third minute of walking but the slope was not significant at the end of the walk (table V, appendix).

IV. DISCUSSION.

The use of walking time as a measure of performance required the man to be consistent in his identification of the symptoms he associates with impending exhaustion. The success of the men in group IV in making this identification can be measured by the small range of variation in the final heart rates and by the extrapolation of the regression of walking time on standing heart rate. If the men had changed the criteria for halting over the range of different walking times we should not expect the projected standing heart rate at zero walking time (205) to agree so well with the average final heart rate (201). By transferring from the subjects to the authors the entire burden of subjectivity, we have been able to raise the correlation between walking time and rectal temperature from 0.83 to 0.98 by the procedure illustrated in figure 5. The critical importance of the final heart rate may depend on the fact that the tilt of the treadmill is increasing minute by minute. In work at a series of fixed loads the attainment of a maximal heart rate does not necessarily coincide with either exhaustion or a maximal oxygen intake. For example, subject JU of Saltin and Stenberg[4] maintained a maximal heart rate over a period of 90 minutes at an oxygen intake slightly below the maximum.

Under the stress of increasing the grade of the treadmill the men reached exhaustion when the heart rate was nearly maximal, an indication that the circulatory system was strained to the utmost. What provides the clue to impending exhaustion? Marx et al.[5] have shown that central blood pressure and total peripheral resistance are maintained up to the point of exhaustion. From indirect evidence it appears that the circulation to the working muscles is maintained.[1] Rowell et al.

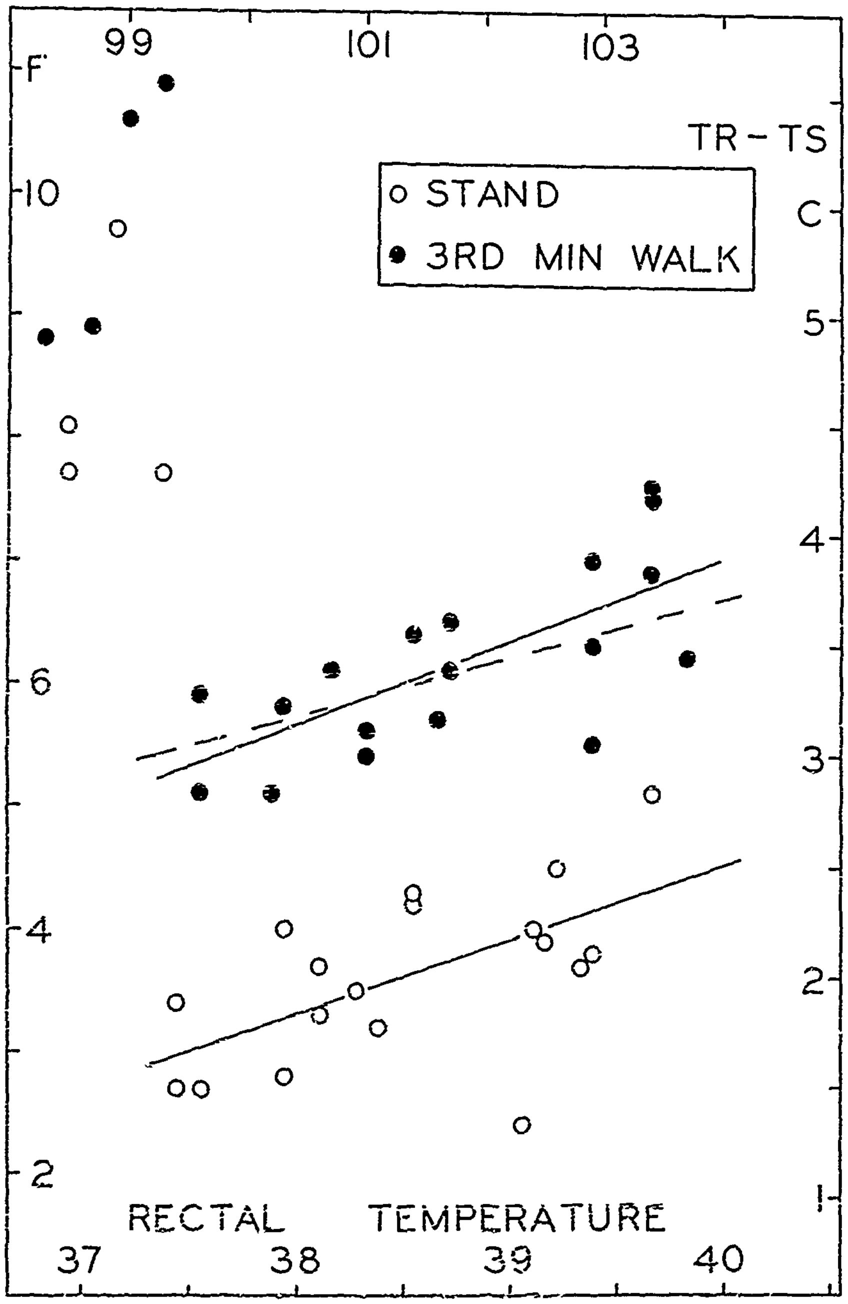

Figure 6. Difference Between Rectal Temperature and Average Skin Temperature Plotted Against Rectal Temperature on Standing Immediately Before the Walk.

The regression lines are derived from the data at 46°C. The points in the upper left hand corner come from one experiment on each subject at 18°C. The dashed line represents the regression of (Tr-Ts) on Tr in the final minute of each walk and during the third minute of the walk.

have shown that blood is drawn from regions such as the liver.[6] In the absence of further information about the peripheral circulation, how may we account for the sensation of impending exhaustion? There is the conventional view that circulation to the head may be impaired.[7] Recently, Rowell et al.[8] have suggested that splanchnic ischemia may contribute to these sensations.

The reduction in walking time at increasing grades and hence in the capacity for work, associated with the increasing initial thermal strain, appears to arise from the circulatory impairment marked by the standing heart rate, which may reflect the state of central blood volume influenced in turn by pooling of blood in the skin and dependent extremities.[8] For this reason the effects of the combination of heat strain and dehydration described earlier[1] are attributed mainly to the increase in body temperature that developed during the 5 hours of exposure to heat and restriction of water intake. Some specific effect of dehydration, perhaps operating through a reduction in plasma volume, may remain since the regression of walking time on standing rectal temperature was steeper in series D than in series II, III and IV. The men in series IV drank enough water at the start to balance the subsequent loss of weight in the tub. This would appear to eliminate gross dehydration as a factor in the present results. No doubt there were some alterations in distribution and composition of the fluids of the body of the types described by Rowell et al.[6] and by Coburn et al.[9]

In the brief walks at increasing grades, the decision to halt was associated with the achievement of a nearly maximal heart rate over a wide range of final rectal temperatures. The situation was quite different in longer walks on a level treadmill in which the heat stress was varied by clothing.[10] The voluntary end-point came at submaximal heart rates and the final heart rate declined significantly with walking time.

The walks at 18°C in Series III and IV were designed to test whether elevated body temperature contributed to the effect of training on the performance of work in the absence of external heat stress.[11] Although more of a training effect (greater endurance and smaller pulse sum) was seen in Series III than in Series IV, there was no way of ruling out the possibility that men in Series IV entered the tests in better condition.

The test of the mask in Series II was included to investigate the possibility that the overheated men would have an increased sensitivity to the added burden of the mask. Under these circumstances, maximal work rates were not attained and the mask had no effect on performance. In the earlier dehydration experiment[1] when respiration was measured, the minute volume at 237 seconds, a time not far from the 252 seconds observed in the mast test, was well below the maximum attained in the longer walks. Apparently, the overheated men were able to compensate for the mask at sub-maximal respiratory conditions.

V. CONDITIONS.

The endurance of men engaged in exhausting work on a treadmill is strongly influenced by the body temperature at the beginning of the work. The higher the initial rectal temperature the shorter is the endurance.

In three groups of four men, the regression of voluntary walking time on rectal temperature was highly significant, with coefficients of correlation of -0.96, -0.79, and -0.86, respectively. From these regressions it may be predicted that at an initial rectal temperature of 41°C, men would be unable to work.

Exhaustion appears to be reached at a maximal heart rate (average 201). The voluntary walking time is closely correlated with the standing heart rate before work is begun (-0.83). From the regression of walking time on standing heart rate, it is predicted that walking time would be zero at a standing heart rate of 205 beats per minute.

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In order to maintain the maximum capacity for exhausting work, troops in the field must avoid overheating as well as dehydration.

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APPENDIX

TABLES

Table I. Subjects

Subject	Height	Weight	Age	Steepest Treadmill Grade Completed
	cm	kg	yr	%
Series I June, July 1966				
FC	172	59.6	55	17
Series II August 1966				
JA	181	72.9	20	18
JC	167	65.6	19	18
JD	178	82.5	21	22
CR	177	78.9	22	19
Series III November, December 1966				
JF	178	60.5	20	19
SS	177	71.5	23	21
TD	178	75.9	21	22
JV	183	66.5	20	21
Series IV January, February 1967				
CB	163	53.4	21	21
LS	173	62.4	20	21
DB	171	71.6	22	21
DG	171	66.1	20	22

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Table II. Summary of Program and Average Data

Day	Room Temp °C	Bag or Tub	Water Intake g	Sweat g	Standing Temp °C	Standing Heart Rate bpm	Walking Time sec	Final Heart Rate bpm
Series I, one man ± bag								
1	46	-	420	389	37.1	92	485	170
26	18	-	0	99	36.5	65	450	180
36	46	+	570	696	38.4	141	339	187
Series II, 4 men ± bag								
1	18	-	0	-	36.5	86	638	189
3	46	-	0	-	37.2	127	492	188
7	46	+	370	-	38.8	144	239	189
9	46	+	626	-	39.0	147	268	192
Series III, 4 men ± bag								
1*	18	+	1000	-	36.9	86	641	196
8,10	46	-	1000	555	37.1	125	638	197
8,10	46	+	1000	742	37.8	155	562	197
3,15	46	-	0	372	37.4	146	552	196
3,15	46	+	0	732	38.1	163	375	196
17*	18	-	1000	-	36.8	86	739	191
Series IV, 4 men ± tub								
1	18	-	-	-	37.1	91	687	202
3	18	-	-	-	37.1	96	739	199
7	18	-	-	-	36.9	91	712	199
10	18	-	-	-	36.8	92	672	196
14	18	-	-	-	37.1	87	712	198
17	46	+	500	29	37.6	126	577	200
21	46	+	500	232	38.2	136	503	200
24**	46	+	500	407	38.5	146	418	201
28	46	+	500	420	39.3	157	257	203
31**	46	+	500	408	39.2	153	327	200
35	18	-	-	-	36.8	91	710	194

*one man absent on day 1 and omitted on day 17
**one man absent

Table III. Effect of Wearing the M17 Protective Mask
on the Work Capacity of Overheated Men

Man	Day	Standing Temp °C	Standing HR bpm	Walking Time sec	Final HR bpm
		Without Mask			
JA	7	38.8	139	196	188
JC	9	39.2	130	307	199
JD	7	38.7	162	196	188
CR	9	38.8	167	322	190
Average		38.9	150	255	191
		With Mask			
JA	9	39.1	141	238	192
JC	7	38.6	115	256	196
JD	9	38.8	150	204	186
CR	7	39.3	158	308	194
Average		39.0	141	252	192

Table IV. Effect of Training With or Without Exposure to Heat on Performance at 18°C

Subject	Time min	Pulse Sum* Before beats	Pulse Sum* After beats	Change percent
		Series III: 4 intervening tests at 46°		
SS	10	1537	1460	-5
TD	11	1831	1734	-5
JV	10	1803	1690	-6
		Series IV: 3 intervening tests at 18°		
CB	10	1527	1474	-3
LS	11	1880	1850	-2
DB	12	2117	2118	0
DG	12	1933	1967	+2
		Series IV: 4 or 5 intervening tests at 46°		
CB	10	1474	1483	+1
LS	11	1850	1841	0
DB	12	2118	2070	-2
DG	12	1967	1869	-5

*Total number of beats during indicated sub-maximal walking times at 18°C before and after intervening training tests at 18°C or 46°C.

Table V. Summary of Regressions of the Form y = a + bx
and Coefficients of Correlation

Series	n	y	x	x or y	a ± SE	b ± SE	r
D	27	walking time, %	Tr, standing	39.62[a]	1636 ± 3[c]	-41.29 ± 5.36[c]	-0.84
II	12	walking time, %	Tr, standing	40.98[a]	1063 ± 3[c]	-25.94 ± 3.96[c]	-0.96
III	16	walking time, %	Tr, standing	40.80[a]	1089 ± 4[c]	-26.69 ± 5.60[c]	-0.79
IV	18	walking time, %	Tr, standing	40.95[a]	1240 ± 3[c]	-30.28 ± 4.43[c]	-0.86
IV	18	walking time, sec	Tr, end tub	40.42[a]	7736 ± 16[c]	-191.39 ± 24.12[c]	-0.89
IV	18	walking time, sec	Tr, standing	40.99[a]	7100 ± 19[c]	-173.23 ± 27.29[c]	-0.85
IV	18	walking time, sec	Tr, end walk	41.28[a]	7280 ± 18[c]	-176.36 ± 26.95[c]	-0.85
IV	18	walking time, sec	Heart rate, standing	204.9[a]	1407 ± 20[c]	-6.87 ± 1.16[c]	-0.83
IV	18	walking time, sec (interpolated)	Tr, standing	42.42[a]	7642 ± 18[c]	-189.07 ± 26.46[c]	-0.87
IV	18	walking time, sec (extrapolated)	Tr, standing	40.41[a]	814 ± 6[c]	-201.76 ± 9.34[c]	-0.98
IV	18	Ts, standing	Tr, standing	36.07[b]	10.79 ± 0.05[c]	0.6678 ± 0.112[c]	-0.83
IV	18	Ts, 3rd min, walk	Tr, 3rd min, walk	34.68[b]	10.51 ± 0.04[c]	0.6400 ± 0.099[c]	0.58
IV	18	Ts, end walk	Tr, end walk	34.67[b]	7.22 ± 0.07[c]	0.7266 ± 0.189[d]	0.69
IV	18	(Tr-Ts), standing	Tr, standing	1.76[b]	-10.78 ± 0.08[c]	0.3319 ± 0.112[d]	0.60
IV	18	(Tr-Ts), 3rd min walk	Tr, 3rd min, walk	3.05[b]	-11.43 ± 0.07[c]	0.3834 ± 0.095[d]	0.71
IV	18	(Tr-Ts), end walk	Tr, end walk	3.11[b]	-7.18 ± 0.12[c]	0.2724 ± 0.188	0.34

a – values of x when y = 0
b – values of y when x = 37.78°C
c – significant above 99.9%
d – significant between 99 and 99.9%
Tr – rectal temperature
Ts – skin temperature

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13. ABSTRACT

(U) Men worked to exhaustion on a treadmill at 3.5 mph and a grade beginning at 10 percent and increasing by one percent per minute in a room at 46°C. The men were first overheated by enclosure in a plastic bag or by immersion in a warm bath. Enough water was drunk to prevent dehydration. When the initial rectal temperature was increased from 36.9 to 39.8°C the walking time decreased from 700 to 200 seconds. The final heart rate was nearly the same for all thermal conditions and averaged 201 bpm. Effects of dehydration on endurance in exhausting work at 46°C, reported previously, appear to be due mainly to overheating during the period of water restriction.

14. KEYWORDS.

Heat stress
Dehydration
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Grade walking
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